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GA-C24578

JANUARY 2004

TEST REPORT – DIRECT PART MARK TEST PROGRAM
DIRECT PART MARK MICROSCOPY TEST PROGRAM

PREPARED

FOR

OO-ALC/LGHEL

BY

AGING LANDING GEAR LIFE
EXTENSION PROGRAM

PREPARED UNDER
CONTRACT GS-23F-0150L
FOR OGDEN AIR LOGISTICS CENTER
HILL AFB, UTAH

PROJECT 39135

GENERAL ATOMICS

GA-C24578
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SIGNATURE PAGE

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AGING LANDING GEAR LIFE EXTENSION PROGRAM

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TABLE OF CONTENTS

INTRODUCTION

Under the Aging Landing Gear Life Extension (ALGLE) Program, a microscopy test program was conducted for geometry characterization and microstructure characterization of machine readable marks that are applied with direct part marking (DPM) processes. OO-ALC/LGHEL is working to qualify DPM processes and machine readable marks for marking recoverable landing gear parts. The test program was to determine if the machine readable marks have problematic geometry features or problematic microstructure features that would degrade the material properties of a part. Additionally, for the test program, the marks were considered controlled flaws, and a focus of the test program was to distinguish problematic features beyond the inherent controlled flaw size of the mark cell dimensions.

The test program was a research and development effort. Before the test program was conducted, research into existing documents uncovered several test reports on the geometry characterization and the microstructure characterization of machine readable marks applied with DPM processes. Most of the documents provided a general overview of one mark on representative aircraft engine materials. This test program focused on several marks on representative landing gear materials. Specifically, the materials were high strength steel and high strength aluminum. If no problematic features were found, then more detailed testing could be conducted to include more materials, more surfaces, and more topographies. Also, if no problematic features were found, or to determine the severity of the problematic features, then additional material characterization such as fatigue testing or stress corrosion cracking testing could be conducted.

The test program did not consider the full complexity of adapting a serial number tracking system based on machine readable marks, but the test program was a necessary requirement to review the technology and to provide a data package to assist in the decision making processes.

OBJECTIVES

The objectives were: to perform a geometry characterization and a microstructure characterization of marks applied with direct part marking (DPM) processes; to determine if the marks have problematic geometry features or problematic microstructure features that would degrade the material properties of a part; and to distinguish problematic features beyond the inherent controlled flaw size of the mark cell dimensions.

TEST MATRIX

Test Matrix

Symbol

Data Matrix™

Data

20 Alphanumeric Characters: XXXXXXXXXXXXXXXXXXXX

(Representative Mark, Not to Scale)

DPM Processes

Dot Peen
LaserShot™ Peen
Micro-Mill
Laser Bond
Laser Etch
Gas Assisted Laser Etch (GALE)
Laser Engrave
Laser Induced Surface Improvement (LISI)
Vibropeen (Not a Machine Readable Mark)

Materials

Steel, 4340, 260 ksi UTS, Marked After Heat Treat
Steel, 4340, 260ksi UTS, Marked Before Heat Treat
Aluminum, 7075-T73, 60 ksi UTS

Surfaces

Marking Surface
Flat Surface

Topographies

Smooth Surface, 125RMS

Test Matrix Discussion

The test matrix was selected to provide sufficient information to perform geometry characterization and microstructure characterization of marks applied with DPM processes. If marks were found to have no problematic features for the selected test matrix of *Symbol*, *Data*, *DPM Processes*, *Materials*, *Surfaces*, and *Topographies*, then the test matrix should be expanded. Additionally, material characterization such as fatigue testing or stress corrosion cracking testing should be conducted to determine the severity of the inherent controlled flaw dimensions for steel and aluminum. If marks were found to have problematic features, then methods to eliminate the problematic features should be investigated or additional material characterization such as fatigue testing or stress corrosion cracking testing should be conducted to determine the severity of the problematic features for steel and aluminum.

Symbol

The Data Matrix™ symbol was selected because it is the dominant machine readable mark for DPM. A Data Matrix™ symbol may contain several hundred characters in a relatively small space.

Data

The data content of 20 characters was selected because it provides sufficient information to track a part. In addition, the data content meets the objectives of the test program. For implementation, the data content would have to be determined by the Department of Defense of the USAF.

DPM Processes

The DPM processes were selected based on the NASA Technical Handbook 6003. Most of the selected processes were reported to provide safe marks for safety critical parts. All the selected processes were reported to provide lifetime traceability. Several processes were omitted from the test program because the processes were: under development, reported not to provide lifetime traceability, and/or offered no advantages over other processes that were already selected. Table 1 outlines the DPM processes that were selected and omitted.

Materials

The 4340 steel and the 7075-T73 aluminum were selected for material availability. Both materials are representative of landing gear materials and both materials duplicate the strength, hardness, and surface finish of landing gear materials.

The marks were applied to the base materials before any protective coatings were applied. Marks must be applied to the base materials if they are to survive an overhaul environment. Note that marks may be applied to the protective coatings without damaging the protective coating or the base material. These marks may survive an operational environment. However, these marks would not survive an overhaul environment unless they penetrate into the base material. If they penetrate into the base material, the functionality of the protective coating may be compromised near the mark.

The steel was marked before and after heat treatment to determine if the marks survive heat treatment. Applying the marks after heat treatment allows existing parts to be marked. Applying the mark before heat treatment is consistent with existing landing gear practices of applying the serial number before heat treatment. In addition, the marks may be more easily applied before heat treatment. If the marks degrade the material properties, the heat treatment process may mitigate any degrading effects.

Surfaces

The flat surface was selected for ease of manufacture, delivery, and processing of the coupons. Marks reportedly read well on flat surfaces. Marks also reportedly read well on curved surfaces provided that the marks occupy a maximum of one third of the diameter of the curve.

Topographies

The smooth surface with a surface roughness of 125RMS was selected because it is a typical surface roughness for landing gear parts. Marks reportedly read well for surface roughness ranges of 64RMS to 256RMS.

Table 1: DPM Process Selection

Included DPM Processes

Process	Safe for Part	Traceability	Comments
Dot Peen	Safe	Lifetime	
LaserShot™ Peen	Safe	Lifetime	
Micro-Mill	Safe	Lifetime	
Laser Bond	Safe	Lifetime	
Laser Etch	Unknown	Lifetime	• May degrade the material.
Gas Assisted Laser Etch (GALE)	Unknown	Lifetime	• May degrade the material.
Laser Engrave	Unknown	Lifetime	• May degrade the material.
Laser Induced Surface Improvement (LISI)	Unknown	Lifetime	• May degrade the material.
Vibropeen Steel Stamp	Safe	Lifetime	• Existing USAF processes. • Not machine readable marks. • Included for a comparison between existing USAF processes and other processes.

Omitted DPM Processes

Process	Safe for Part	Traceability	Comments
Abrasive Blast	Safe	Lifetime	• A difficult process to control. • No benefit over the other impression methods.
Build Up (Flame Spray, HVOF)	Safe	Not Lifetime	• Process under development. • Will not survive the overhaul environment. • May survive the operational environment.
Cast / Mold	Safe	Lifetime	• Process under development.
Electro-Chemical Etch	Safe	Lifetime	• No benefit over the impression methods. • May degrade the material.
Forge / Mold	Safe	Lifetime	• Process under development.
Ink / Paint	Safe	Not Lifetime	• May survive the operational environment if applied to a painted surface.
Laser Induced Vapor Deposition (LIVD)	Safe	Lifetime	• Used to apply marks to transparent materials.
Plate and Remove	Safe	Not Lifetime	• Will not survive the overhaul environment. • May survive the operational environment.
Thin Film Deposition	Safe	Not Lifetime	• A difficult process to apply marks to large parts. • Will not survive the overhaul environment. • May survive the operational environment.

TEST PROCEDURES

Coupon Testing

1. The test matrix was developed and the testing was conducted by the ALGLE Program. The test matrix was accomplished with several coupons. The coupon drawings are contained in Appendix A.

Coupon Manufacturing

1. The coupons were manufactured by NorthWest Machining and Manufacturing (NWMM).
2. The coupon manufacturing documentation is contained in Appendix B.

Coupon Marking

1. The coupons were marked by Robotic Vision Systems Incorporated (RVSI).
2. The marking documentation is contained in Appendix C.

Coupon Microscopy

1. The microscopy evaluation was conducted by the ALGLE Program.
   1.1 Optical microscope images of the mark surfaces and the cross sections are contained in Appendix D.
   1.2 SEM images of the mark surfaces and the cross sections are contained in Appendix D.

General Test Procedures

1. The microscopy evaluation was performed for coupons S2A, S2B, and A2A.
   1.1 Geometry characterization was performed for all the marks.
   1.2 Microstructure characterization was performed for dot peen, micro-mill, laser engrave, and vibropeen marks.

Geometric Characterization

1. The marks were examined with an optical microscope at 1X to 50X magnification.
2. Stereo optical microscope images of the marks were taken at 2X magnification.
3. The marks were examined with an SEM at 30X to 1000X magnification.
4. Surface SEM images of the mark cells were taken at 30X magnification.
5. Surface SEM images of the mark cells were taken at 30X magnification on a 45° tilt.
6. The depth of the cells was measured with a dial depth gage. Average values are provided.
7. The depth of the cells was measured with SEM software. Typical values are provided.

Microstructure Characterization

1. The coupons were sectioned and polished to expose a mark cross section that contained a minimum of 5 cells.
2. Microhardness measurements were taken of the exposed cross section away from the marks.
   2.1 ASTM E 384 was used as a guide.
   2.2 For coupons S2A and S2B, a diamond pyramid hardness indenter was used with a 200g load and a 30 second dwell time.
   2.3 For coupons A2A, a diamond pyramid hardness indenter was used with a 100g load and a 30 second dwell time.
   2.4 At least three mircohardness measurements were taken of the base material well away from the cell surface.
   2.5 At least three microhardness measurements were taken at depths less than 0.005inch from the cell surface.
3. Etching the exposed cross section near the marks was performed.
   3.1 ASTM E 407 was used as a guide.
   3.2 For coupons S2A and S2B, , a 2% nital etchant ($2\%HN0_3 + 98\%$ Ethanol (CH_3CH_2OH)) was used.
   3.3 For coupons A2A, a Flick etchant ($9\%HF + 13\%HCl + 78\%H_20$) was used.
   3.4 Stereo optical microscope images were taken of the etched cross section near the mark cells at 500X magnification.

RESULTS AND DISCUSSION

Results

All the test results are presented in terms of the coupon part numbers S2A, S2B, and A2A which contain basic information about the material and when the material was marked. Coupon S2A was 4340 steel (S) that was marked after (A) heat treating to 260 ksi UTS. Coupon S2B was 4340 steel (S) that was marked before (B) heat treating to 260 ksi UTS. Coupon A2A was 7075-T73 aluminum (A) that was marked after (A) heat treating. Detailed test results are contained in Appendix D and Appendix E.

A summary of the test results is contained in Table 2 through Table 7. Table 2 contains data for the depth of the mark cells as measured with a dial depth gage. Table 3 contains data for the depth of mark cells as measured with quantitative SEM software. Table 4 contains summary test results for the microhardness data. Table 5 through Table 7 contain summary cross section images for the mark cells. There are SEM images of the cross sections and optical images of the cross sections after etching.

Geometry Characterization

The marks were examined with an optical microscope and a scanning electron microscope to provide a basic geometry characterization for the marks. The marks were examined at 5X to 1000X magnification. Representative images of the marks are contained in Appendix D. The SEM surface images show the mark cells and the adjacent base material. The dot peen marks had a relatively smooth surface and were consistent with a stylus impacting the surface. The lasershot peen marks had a rounded and depressed surface and were consistent with shock wave impacting the surface. The micro-mill marks had a relatively smooth surface and were consistent with a tool cutting the surface. For the micro-mill marks, damage between cells, due to insufficient cell spacing, was observed. Additionally, for some of the micro-mill marks, very sharp corner radii, which would likely produce high stress concentrations, were present. The laser bond marks had a blistered surface that was consistent with the application of a ceramic coating to the surface. The laser etch, GALE, laser engrave, and LISI mark had droplet features along regularly spaced lines and were consistent with melting and resolidification as a laser traversed the surface. The laser engrave marks had the most obvious features. The machining marks on the coupon surface were visible through several of the laser marks. This is an indication that the marks may not degrade the material, but it is also an indication that the marks would not survive an aggressive environment. The vibropeen marks had gouges consistent with a rapidly vibrating tool irregularly impacting the surface. Based on the geometry characterization, apart from the inherent controlled flaw of the mark, no other obvious material degradation was found. No evidence of micro cracking in the base material was found for any of the marks.

Table 2 and Table 3 contain summaries of the mark cell depths. All the cell depths were measured with a dial depth gage that had an accuracy of 0.0005in. For the marks that were cross sectioned, the cell depths were measured quantitatively with SEM software. There was a very good correlation between the dial depth gage measurement and the SEM measurement. This indicates that the dial depth gage could be used as a simple method of measuring cell depth for mark quality verification and control.

Microstructure Characterization

Microhardness

The test data in Table 4 demonstrates that there was minor hardening and softening for several of the marks on several of the coupons. Some of the effects may be better classified as very minor hardening and softening. None of the effects were deep and all of the effects were less than 0.001in. to 0.002in. from the cell surface. For marks with minor softening, an equivalent controlled flaw size could be considered the mark cell dimensions plus 0.001in. to 0.002in.

For a specific mark, the only observable trend was for the micro-mill mark which had no change in microhardness for all the coupons. The other marks all had minor softening, minor hardening, or no change for the different coupons. These trends were not consistent with minor hardening or minor softening for a particular mark. For a specific coupon, the only observable trend was for the steel coupon that was marked before heat treatment. Very minor hardening for the dot peen mark was observed, and no change for micro-mill or laser engrave marks was observed. This is consistent with marking before heat treatment. The other coupons had minor softening, minor hardening, or no change for the different marks. A possible explanation of the results is that for the different DPM processes, there are two phenomena competing: plastic deformation from the DPM process that results in minor hardening, and heating from the DPM process that results in minor softening.

The minor hardening, the minor softening, and the inconsistent trends indicate that the microhardness data is not able to distinguish any material degradation effects between the DPM processes. Based on the microhardness data, there were no material degradation effects of consequence from the DPM processes for the steel and aluminum. Further material characterization testing, such as fatigue testing or stress corrosion cracking testing, would be required to distinguish any material degradation effects between the DPM processes.

Etched Microstructure

Table 5 through Table 7 contain cross section images of several marks. The SEM images of mark cell cross sections show the basic overview of the mark and the adjacent base material. The optical images of the etched mark cell cross sections show the microstructure of the mark and the adjacent base material.

The etched steel had a typical base material microstructure of tempered martensite with uniform laths at random orientations. Note that the laths of tempered martensite are barely observable at 500X magnification. The etched aluminum had a typical base material microstructure of heat treated, age hardened, aluminum plate with uniformly elongated grains.

For the dot peen marks the etched microstructures had features that are consistent with a stylus impacting the surface. The steel microstructures had uniform laths of tempered martensite up to the cell surface. The aluminum microstructure had grain distortion around the cell surface.

For the micro-mill marks, the etched microstructures had features that are consistent with a tool cutting the surface. The steel microstructures had uniform laths of tempered martensite up to the cell surface. The aluminum microstructure had uniformly elongated grains without distortion up to the cell surface.

For the laser engrave marks, the etched microstructures had features that are consistent with a laser traversing the surface. The microstructure for the steel marked after heat treatment had a shallow heat affected zone approximately 0.0005in. thick at the cell surface. The shallow heat affected zone is consistent with a thin, connected layer of untempered martensite that results from very rapid melting, resolidification, and transformation of the steel after the final heat treatment. The steel would easily transform to untempered martensite during the very rapid resolidification. The transition microstructure between the untempered martensite and the tempered martensite was less than approximately 0.0001in. The microstructure for the steel marked before heat treatment had relatively uniform laths of tempered martensite up to the cell surface. The relatively uniform laths of tempered martensite are consistent with very rapid melting, resolidification, and transformation of the steel before the final heat treatment. A shallow heat affected zone was not present. The complete heat treating process of austenitizing, quenching, and tempering would easily transform any prior shallow heat affected zone of untempered martensite to tempered martensite. The aluminum marked after heat treatment had a shallow heat affected zone approximately 0.001in. thick at the cell surface. The shallow heat affected zone is consistent with a thin layer of as cast aluminum that results from very rapid melting and resolidification of aluminum after heat treatment. The transition microstructure between the as cast aluminum and the age hardened aluminum was less than approximately 0.0001in.

For the vibropeen marks, the etched microstructures had features that are consistent with a vibrating tool irregularly impacting the surface. The steel microstructure had uniform laths of tempered martensite near the cell surface. The aluminum microstructure had slightly deformed grains near the cell surface. For both microstructures, there was some edge distortion which could be a result of minor plastic deformation approximately 0.0005in deep, or an artifact of the microscopy evaluation such as image distortion, or epoxy mount separation.

No problematic microstructure features were found for the dot peen, micro-mill, or vibropeen marks. Problematic microstructure features were found for the laser engrave mark applied after heat treatment. A heat affected zone is not an acceptable material condition for the surface of a landing gear part. The material in the heat affected zone would be expected to crack and consequently propagate a crack into the base material either immediately under normal loading or prematurely in fatigue loading. For steel, the shallow heat affected zone is consistent with untempered, low toughness, martensite, which would be expected to crack immediately under normal loading. Untempered martensite also has a very high susceptibility to stress corrosion cracking. For aluminum, the shallow heat affected zone is consistent with as cast, low strength, aluminum which would be expected to crack prematurely under normal fatigue loading. For the marks with the shallow heat affected zone, an equivalent controlled flaw size could be considered the mark cell dimensions plus 0.001in. The shallow heat affected zone is not a significant increase for the equivalent controlled flaw size, but it is a significant and problematic microstructure feature for crack initiation. Further material characterization testing, such as fatigue testing or stress corrosion cracking testing, would be required to determine the severity of the problematic features for steel and aluminum, or to provide test data to demonstrate that a shallow heat affected zone for a laser engrave mark on a landing gear marking surface may be an acceptable material condition. No problematic microstructure features were found for the laser engrave mark applied before heat treatment.

Table 2: Summary of Mark Cell Depths
Average Depth Based on 3 Dial Gage Measurements *
S2A: 4340 Steel (260 ksi UTS) Marked After Heat Treatment
S2B: 4340 Steel (260 ksi UTS) Marked Before Heat Treatment
A2A: 7075-T73 Aluminum Marked After Heat Treatment

DPM Process	Coupon S2A in	Coupon S2B in	Coupon A2A in
1 - Dot Peen	0.001	0.002	0.004
2 - LaserShot Peen	0.000	0.000	0.000
3 - Micro-Mill	0.028	0.027	0.027
4 - Laser Bond	0.000	0.000	0.000
5 - Laser Etch	0.000	0.000	0.001
6 - GALE	0.000	0.000	0.000
7 - Laser Engrave	0.001	0.003	0.005
8 - LISI	0.000	0.000	0.000
9 - Vibropeen	0.002	0.004	0.002

*A depth of 0.000in. indicates that no depth measurement could be taken.

Table 3: Summary of Mark Cell Depths *
Typical Depth Based on Direct Cross Section Measurement with Quantitative SEM Software *
S2A: 4340 Steel (260 ksi UTS) Marked After Heat Treatment
S2B: 4340 Steel (260 ksi UTS) Marked Before Heat Treatment
A2A: 7075-T73 Aluminum Marked After Heat Treatment

Coupon	DPM Process	Cell Depth Relative to Coupon Surface in (μm)	Cell Depth Range Maximum Protrusion - Maximum Depth in (μm)
S2A	1 - Dot Peen	0.0014 (36)	0.0015 (38)
	3 - Micro-Mill	0.0290 (725)	0.0290 (735)
	7 - Laser Engrave	0.0016 (40)	0.0020 (50)
	9 - Vibropeen		
	Heavy Pressure	0.0033 (85)	0.0046 (116)
	Medium Pressure	0.0037 (95)	0.0044 (111)
	Light Pressure	0.0011 (28)	0.0017 (42)
S2B	1 - Dot Peen	0.0022 (56)	0.0022 (56)
	3 - Micro-Mill	0.0250 (625)	0.0250 (625)
	7 - Laser Engrave	0.0044 (111)	0.0044 (111)
A2A	1 - Dot Peen	0.0069 (174)	0.0069 (174)
	3 - Micro-Mill	0.0290 (727)	0.0300 (760)
	7 - Laser Engrave	0.0090 (239)	0.0100 (262)
	9 - Vibropeen		
	Heavy Pressure	0.0021 (54)	0.0038 (97)
	Medium Pressure	0.0010 (26)	0.0022 (55)
	Light Pressure	0.0014 (35)	0.0023 (59)

*The magnifications for the measurements ranged between 30X and 250X. The depth of the machining marks on the coupon surface from peak to trough were typically 0.0004in. The reference plane of the surface of the coupon was equated with the peaks of the machining marks.

Table 4: Summary of Mark Microhardness Data at Depths Less than 0.005in. from the Cell Surface
S2A: 4340 Steel (260 ksi UTS) Marked After Heat Treatment
S2B: 4340 Steel (260 ksi UTS) Marked Before Heat Treatment
A2A: 7075-T73 Aluminum Marked After Heat Treatment

Coupon	DPM Process	Diamond Pyramid Hardness DPH - (kg/mm^2) Average ± Standard Deviation	Percent Change	Hardening Softening
S2A	Material	578.3 ± 11.5	**	**
	1 - Dot Peen	553.3 ± 17.4	-3.9%	Minor Softening
	3 – Micro-Mill	576.4 ± 4.0	-0.3%	No Change
	7 - Laser Engrave	578.8 ± 5.2	+0.1%	No Change
	9 - Vibropeen	594.6 ± 19.2	+2.8%	Minor Hardening
S2B	Material	577.0 ± 5.9	**	**
	1 - Dot Peen	585.3 ± 2.5	+1.5%	Minor Hardening
	3 – Micro-Mill	580.6 ± 3.5	+0.6%	No Change
	7 - Laser Engrave	574.8 ± 3.7	-0.4%	No Change
A2A	Material	142.8 ± 4.3	**	**
	1 - Dot Peen	157.9 ± 6.6	+10.5%	Minor Hardening
	3 – Micro-Mill	143.0 ± 6.5	+0.1%	No Change
	7 - Laser Engrave	131.5 ± 4.0	-7.9%	Minor Softening
	9 - Vibropeen	138.3 ± 3.4	-3.2%	Minor Softening

Table 5: Cross Section Images of Marks on Coupon S2A
S2A: 4340 Steel (260 ksi UTS) Marked After Heat Treatment

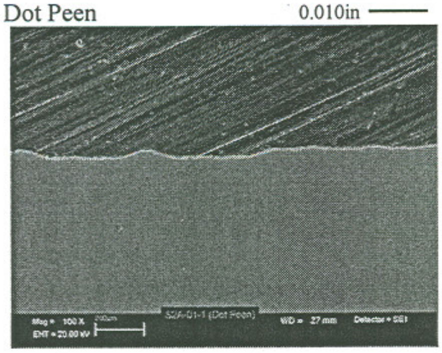
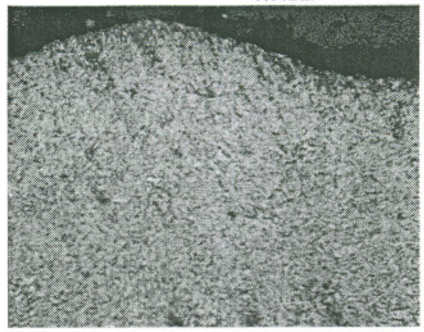
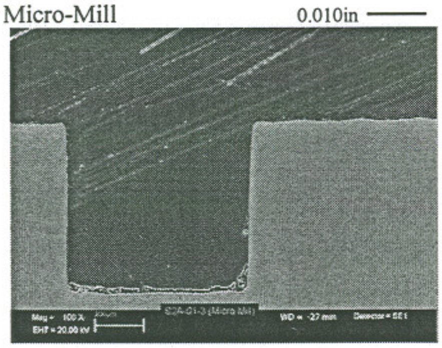
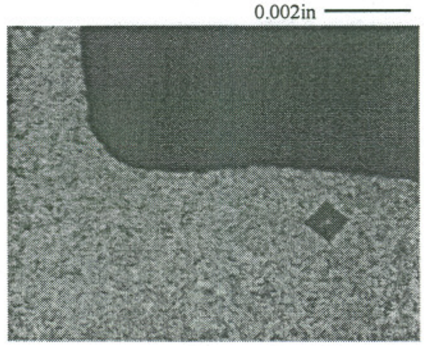
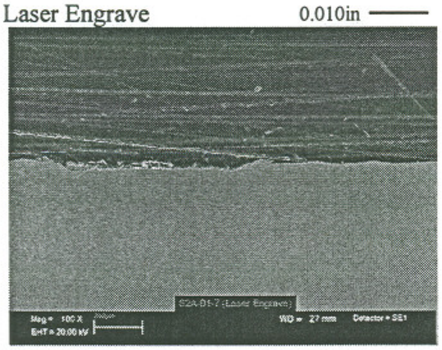
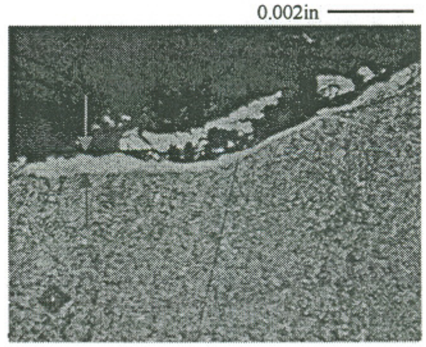
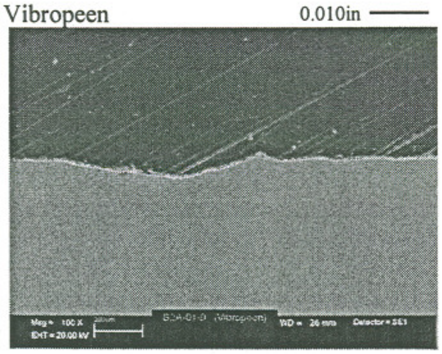
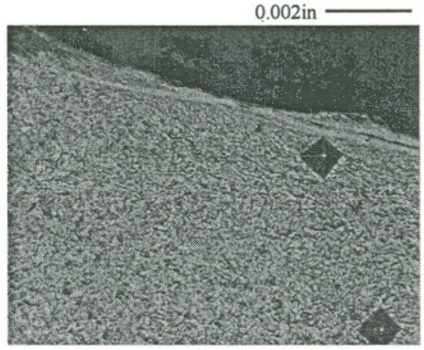
SEM Image of Cell Cross Section	Optical Image of Etched Microstructure
1 – Dot Peen 0.010in 	0.002in 
3 – Micro-Mill 0.010in 	0.002in 
7 – Laser Engrave 0.010in 	0.002in 
9 – Vibropeen 0.010in 	0.002in 

Table 6: Cross Section Images of Marks on Coupon S2B
S2B: 4340 Steel (260 ksi UTS) Marked Before Heat Treatment

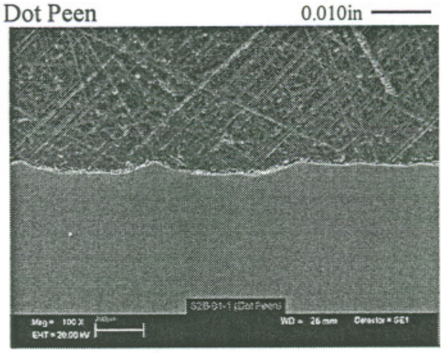
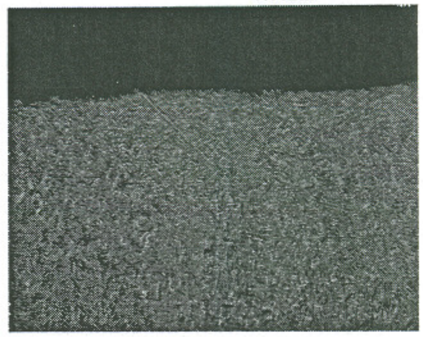
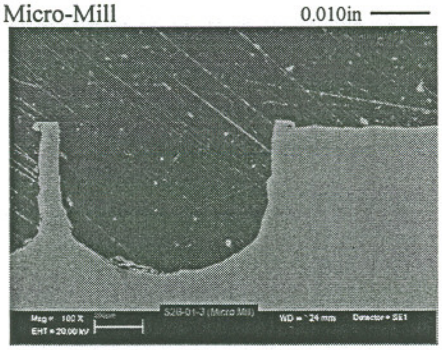
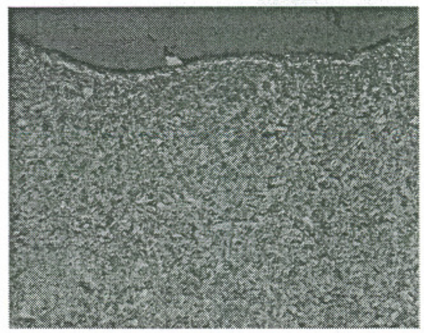
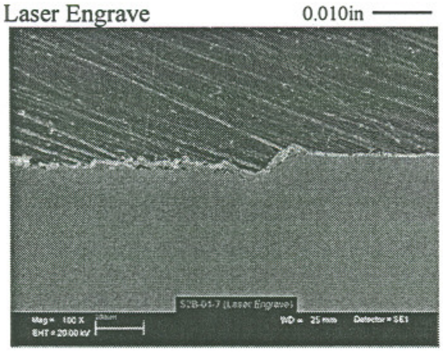
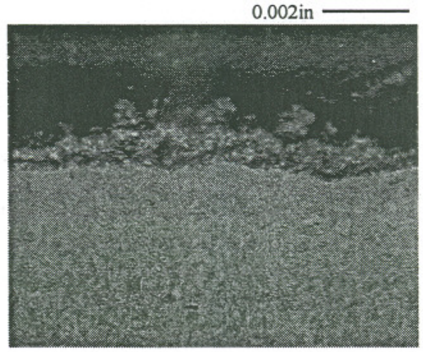
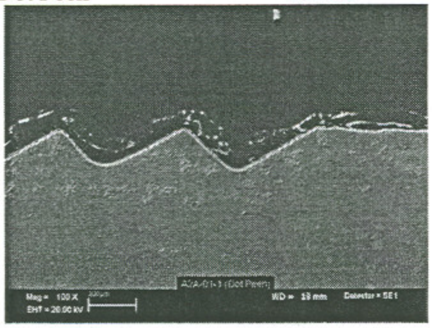
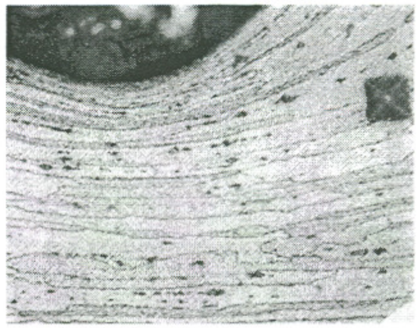
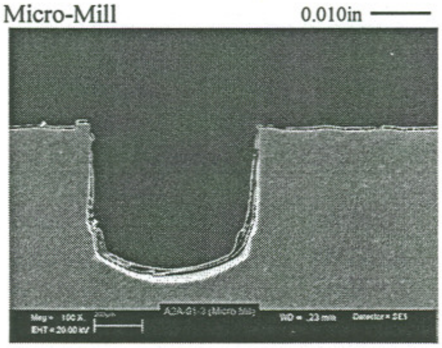
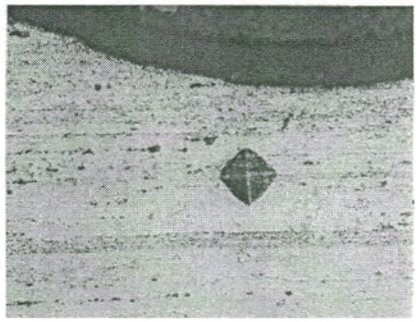
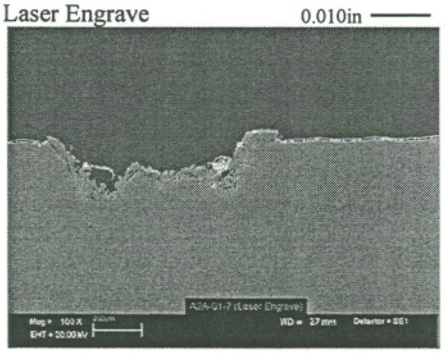
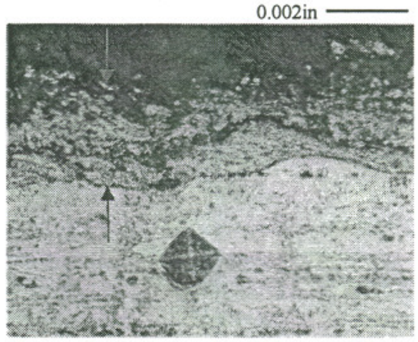
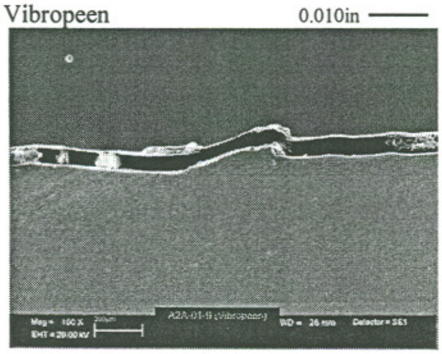
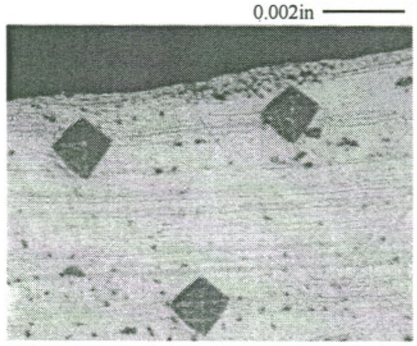
SEM Image of Cell Cross Section	Optical Image of Etched Microstructure
1 – Dot Peen 0.010in 	0.002in 
3 – Micro-Mill 0.010in 	0.002in 
7 – Laser Engrave 0.010in 	0.002in 

Table 7: Cross Section Images of Marks on Coupon A2A
A2A: 7075-T73 Aluminum Marked After Heat Treatment

SEM Image of Cell Cross Section	Optical Image of Etched Microstructure
1 – Dot Peen 0.010in 	0.002in 
3 – Micro-Mill 0.010in 	0.002in 
7 – Laser Engrave 0.010in 	0.002in 
9 – Vibropeen 0.010in 	0.002in 

CONCLUSIONS

The microscopy test program was conducted for geometry characterization and microstructure characterization of machine readable marks that are applied with DPM processes. The test program was to determine if the machine readable marks have problematic geometry features or problematic microstructure features that would degrade the material properties of a part. The test program evaluated marks on high strength steel and high strength aluminum.

The geometry characterization provided a basic overview of the marks and identified microscopic features consistent with the DPM processes. The geometry characterization identified potential problems for micro-mill marks with the damage between cells due to insufficient cell spacing, and stress concentrations due to very sharp corner radii. No evidence of micro cracking in the base material was found for any of the marks.

The microhardness characterization identified minor hardening and softening for several of the marks. The microhardness data was not able to distinguish any material degradation effects. The microhardness data indicated that there were no material degradation effects of consequence from the DPM processes.

The etched microstructures identified: no problematic microstructure features for the dot peen, micro-mill, or vibropeen marks applied before or after heat treatment; no problematic microstructure features for the laser engrave mark applied before heat treatment; and problematic microstructure features for the laser engrave mark applied after heat treatment. The problematic microstructure features were shallow heat affected zones approximately 0.0005in to 0.001in thick.

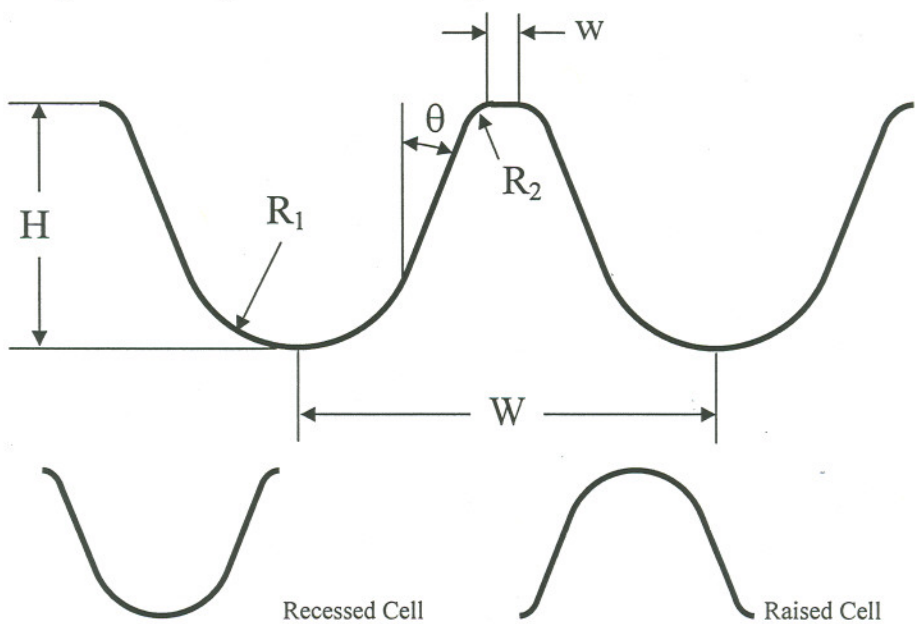
Further material characterization testing, such as fatigue testing or stress corrosion cracking, would be required to determine the severity of the problematic microstructure features for the DPM processes, or to provide test data to demonstrate that a shallow heat affected zone for a laser engrave mark on a landing gear marking surface may be an acceptable material condition.

RECOMMENDATIONS

Based on the test data, it is recommended to pursue development and testing to eliminate the problematic features that were found for several of the marks. No problematic features were found for the dot peen mark. Problematic features of damage between cells due to insufficient cell spacing, and stress concentrations due to very sharp corner radii, were found for the micro-mill mark. No problematic features were found for the laser engrave mark applied before heat treatment. Problematic features of a shallow heat affected zone were found for the laser engrave marks applied after heat treatment. The test data indicates that a round cell design that includes tapered sides and corner radii would reduce cell damage and stress concentration effects. A proposed cell design for dot peen, micro-mill, and laser engrave marks is provided in Figure 1. Finally, it is recommended to investigate removing the shallow heat affected zone from the laser engrave marks with an abrasive blasting process. The shallow heat affected zone is similar to a shallow grinding burn for a landing gear part. The current practice is to garnet blast the part to remove the shallow grinding burn. If the part then passes a nital etch inspection, the part is considered serviceable.

For a complete material characterization, it is recommended to conduct fatigue testing and stress corrosion cracking (SCC) testing. The fatigue testing and SCC testing should be conducted to determine the combined severity of the inherent controlled flaw size of the mark and any additional problematic features of the mark. The fatigue and SCC testing would likely require a significant development effort. It would likely include testing marks on standard coupons to estimate the reduction in fatigue life or SCC resistance at a specific stress level. A comparison of the coupon test data with part specific stress analysis data would be required to determine a suitable mark location. Full scale fatigue testing and SCC testing of the parts or assemblies may be required to validate the determination of a suitable mark location from the coupon test data and the part specific stress analysis. This level of testing would qualify the mark and the mark location for the parts or assemblies.

Figure 1: Proposed Cell Design for Future Test Programs

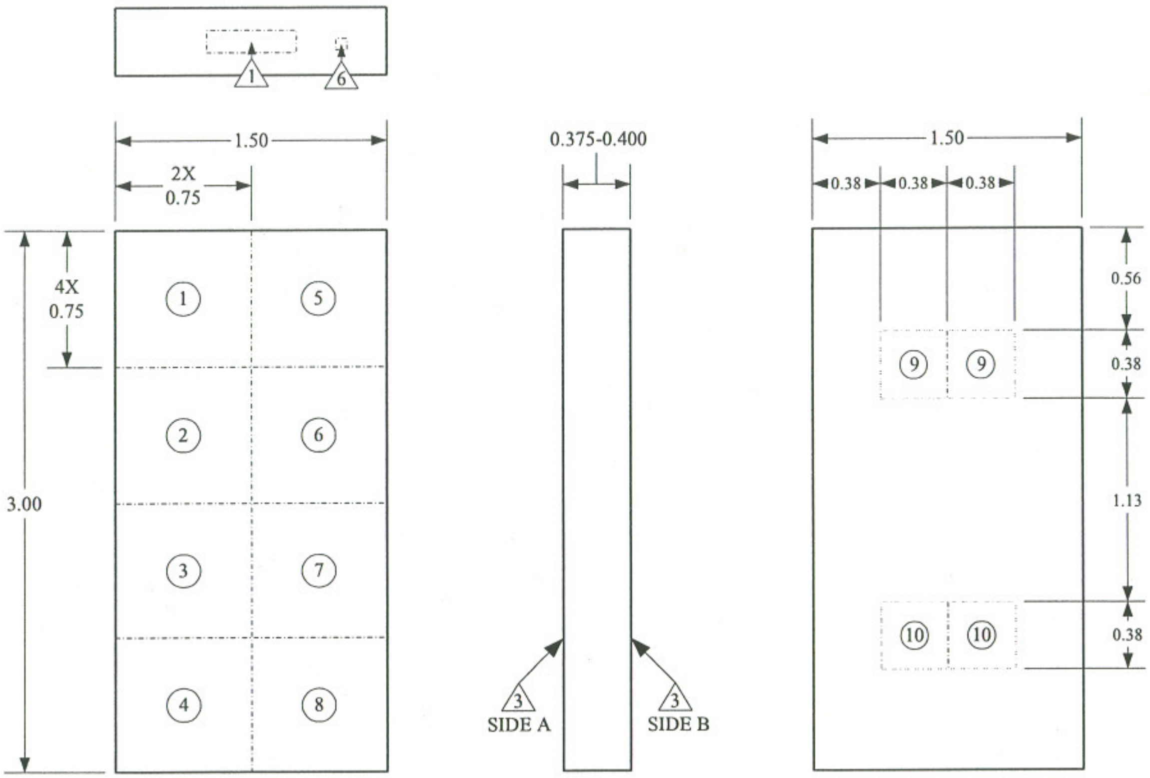


- Proposed Cell Design Applicable to Recessed Cells and Raised Cells
- H: Deep Enough to Survive Overhaul Processes with Reasonable Masking
- W, w: Sufficient Cell Spacing to Reduce Cell Damage
- θ: Draft Angle to Reduce Cell Damage and Cell Stress Concentration (Kt)
- R_1, R_2: Radii to Reduce Cell Damage and Cell Stress Concentration (Kt)

APPENDIX A
COUPON DRAWINGS

COUPON DRAWINGS: REVISION C

COUPON



NOTES

1. SERIALIZE THE COUPONS S2A-O1 TO S2A-12 AT NOTED LOCATION USING 0.25 IMPRESSION STAMP,0.004-0.008 DEEP
2. HEAT TREAT AND PROCESS TO 260-280 KSI ULTIMATE TENSILE STRENGTH PER AMS-H-6875, MAXIMUM ALLOWABLE DECARBURIZATION 0.003
3. 0.025 125/64 M BEFORE 2, 125/64 M AFTER 2
4. BREAK ALL SHARP EDGES 0.005-0.015
5. FLUORESCENT MAGNETIC PARTICLE INSPECT PER ASTM E1444
6. FOR COUPONS WITH EVEN SERIAL NUMBERS: PERFORM ROCKWELL HARDNESS C TEST PER ASTM A370 AT NOTED LOCATION
7. FOR COUPONS WITH EVEN SERIAL NUMBERS: PERFORM SURFACE ROUGHNESS MEASUREMENT PER ASME B46.1

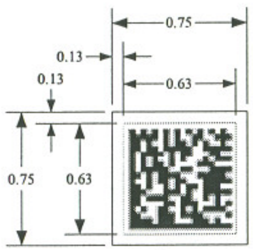
(1) – (10) FOR COUPONS S2A-01 TO S2A-06: MARK WITH DATA MATRIX™ SYMBOLS PER TABLE I REQUIREMENTS

ALGLE PROGRAM	TITLE: COUPON	DRAWING NUMBER: S2A	REVISION: C	DIMENSIONS: ALL DIMENSIONS IN INCHES	TOLERANCES: UNLESS OTHERWISE NOTED X.X = ± 0.1 X.XX = ± 0.05 ANGLES = ± 0.5°	DRAWN: JOHN COATES
DPM EVALUATION	MATERIAL: 4340 PER AMS 6415	DATE: 3/9/01	SHEET: 1 OF 2	SCALE: NOT TO SCALE		CHECKED: FRANK ZUECH

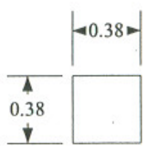
TABLE I: DATA MATRIX™ REQUIREMENTS

1. DOT PEEN MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027), 0.008-0.016 DEEP
2. LASERSHOT™ PEEN MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027), 0.008-0.016 DEEP
3. MICRO-MILL MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027), 0.024-0.032 DEEP
4. LASER BOND MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027)
5. LASER ETCH MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027)
6. GAS ASSIST LASER ETCH (GALE) MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027)
7. LASER ENGRAVE MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027), 0.008-0.016 DEEP
8. LASER INDUCE SURFACE IMPROVEMENT (LISI) MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027)
9. VIBRA-ETCH MARK IN DETAIL I.B PER OO-ALC/LITP PROCEDURE (NOT A MACHINE READABLE MARK)
10. IMPRESSION STAMP MARK IN DETAIL I.B PER OO-ALC/LITP PROCEDURE (NOT A MACHINE READABLE MARK)

DETAIL I.A*



DETAIL I.B*



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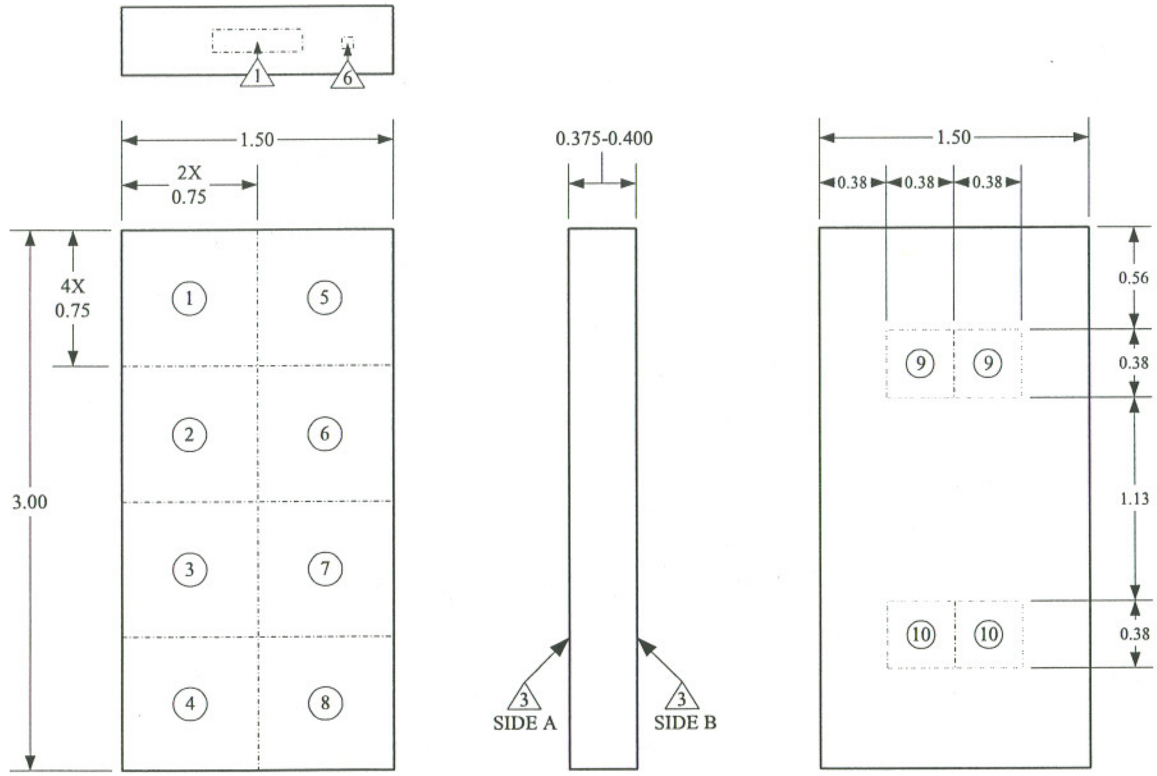
6	XXXXXXXXXXXXXXXXXXX6
7	XXXXXXXXXXXXXXXXXXX7
8	XXXXXXXXXXXXXXXXXXX8
9	ALPHANUMERIC CHARACTER
10	ALPHANUMERIC CHARACTER

*DIMENSIONS INDICATE THE MAXIMUM ALLOWABLE AREA FOR MARKING

ALGLE PROGRAM	TITLE COUPON	DRAWING NUMBER S2A	REVISION C	DIMENSIONS ALL DIMENSIONS IN INCHES	TOLERANCES UNLESS OTHERWISE NOTED X.X = ± 0.1 X.XX = ± 0.05 ANGLES = ± 0.5°	DRAWN JOHN COATES
DPM EVALUATION	MATERIAL 4340 PER AMS 6415	DATE 3/9/01	SHEET 2 OF 2	SCALE NOT TO SCALE		CHECKED FRANK ZUECH

COUPON



NOTES

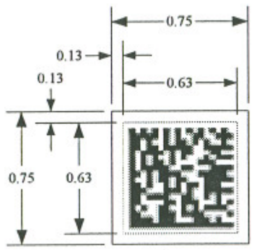
1 (in triangle)	SERIALIZE THE COUPONS S2B-01 TO S2B-06 AT NOTED LOCATION USING 0.25 IMPRESSION STAMP,0.004-0.008 DEEP
2	HEAT TREAT AND PROCESS TO 260-280 KSI ULTIMATE TENSILE STRENGTH PER AMS-H-6875, MAXIMUM ALLOWABLE DECARBURIZATION 0.003
3 (in triangle)	0.025 125 / 64 M BEFORE 2, 125 / 64 M AFTER 2
4	BREAK ALL SHARP EDGES 0.005-0.015
5	i) FLUORESCENT MAGNETIC PARTICLE INSPECT PER ASTM E1444 ii) INSPECT BEFORE AND AFTER MARKING 1 – 10
6 (in triangle)	FOR COUPONS WITH EVEN SERIAL NUMBERS: PERFORM ROCKWELL HARDNESS C TEST PER ASTM A370 AT NOTED LOCATION
7	FOR COUPONS WITH EVEN SERIAL NUMBERS: PERFORM SURFACE ROUGHNESS MEASUREMENT PER ASME B46.1
1 – 10	i) MARK BEFORE 2 ii) FOR COUPONS S2B-01 TO S2B-06: MARK WITH DATA MATRIX™ SYMBOLS PER TABLE I REQUIREMENTS

ALGLE PROGRAM ALGLE	TITLE COUPON	DRAWING NUMBER S2B	REVISION C	DIMENSIONS ALL DIMENSIONS IN INCHES	TOLERANCES UNLESS OTHERWISE NOTED X.X = ± 0.1 X.XX = ± 0.05 ANGLES = ± 0.5°	DRAWN JOHN COATES
DPM EVALUATION	MATERIAL 4340 PER AMS 6415	DATE 3/9/01	SHEET 1 OF 2	SCALE NOT TO SCALE		CHECKED FRANK ZUECH

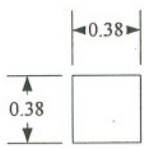
TABLE I: DATA MATRIX™ REQUIREMENTS

1. DOT PEEN MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027), 0.008-0.016 DEEP
2. LASERSHOT™ PEEN MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027), 0.008-0.016 DEEP
3. MICRO-MILL MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027), 0.024-0.032 DEEP
4. LASER BOND MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027)
5. LASER ETCH MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027)
6. GAS ASSIST LASER ETCH (GALE) MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027)
7. LASER ENGRAVE MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027), 0.008-0.016 DEEP
8. LASER INDUCE SURFACE IMPROVEMENT (LISI) MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027)
9. VIBRA-ETCH MARK IN DETAIL I.B PER OO-ALC/LITP PROCEDURE (NOT A MACHINE READABLE MARK)
10. IMPRESSION STAMP MARK IN DETAIL I.B PER OO-ALC/LITP PROCEDURE (NOT A MACHINE READABLE MARK)

DETAIL I.A*



DETAIL I.B*



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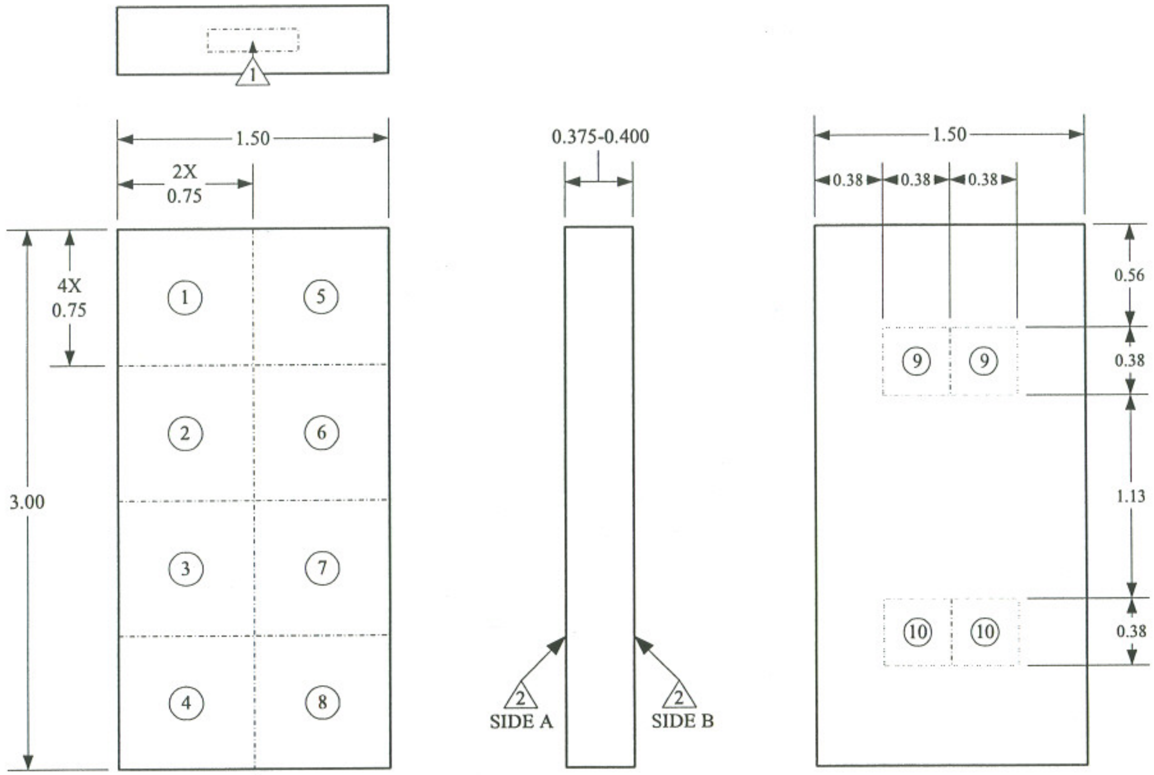
8	XXXXXXXXXXXXXXXXXXX8
9	ALPHANUMERIC CHARACTER
10	ALPHANUMERIC CHARACTER

*DIMENSIONS INDICATE THE MAXIMUM ALLOWABLE AREA FOR MARKING

ALGLE PROGRAM	TITLE COUPON	DRAWING NUMBER S2B	REVISION C	DIMENSIONS ALL DIMENSIONS IN INCHES	TOLERANCES UNLESS OTHERWISE NOTED X.X = ± 0.1 X.XX = ± 0.05 ANGLES = ± 0.5°	DRAWN JOHN COATES
DPM EVALUATION	MATERIAL 4340 PER AMS 6415	DATE 3/9/01	SHEET 2 OF 2	SCALE NOT TO SCALE		CHECKED FRANK ZUECH

COUPON



NOTES

1. SERIALIZE THE COUPONS A2A-O1 TO A2A-12 AT NOTED LOCATION USING 0.25 IMPRESSION STAMP, 0.004-0.008 DEEP
2. 0.025 √ 125/64 M
3. BREAK ALL SHARP EDGES 0.005-0.015
4. FLUORESCENT PENETRANT INSPECT PER ASTM E1417
5. FOR COUPONS WITH EVEN SERIAL NUMBERS: PERFORM CONDUCTIVITY TESTS PER MIL-STD-1537
6. FOR COUPONS WITH EVEN SERIAL NUMBERS: PERFORM SURFACE ROUGHNESS MEASUREMENT PER ASME B46.1

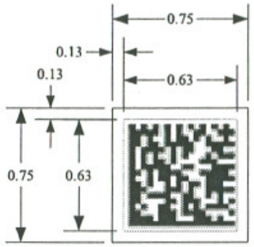
1 – 10 FOR COUPONS A2A-01 TO A2A-06: MARK WITH DATA MATRIX™ SYMBOLS PER TABLE I REQUIREMENTS

ALGLE PROGRAM ALGLE	TITLE COUPON	DRAWING NUMBER A2A	REVISION C	DIMENSIONS ALL DIMENSIONS IN INCHES	TOLERANCES UNLESS OTHERWISE NOTED X.X = ± 0.1 X.XX = ± 0.05 ANGLES = ± 0.5°	DRAWN JOHN COATES
DPM EVALUATION	MATERIAL 7075-T7351 PER AMS 4078 (0.5 INCH PLATE)	DATE 3/9/01	SHEET 1 OF 2	SCALE NOT TO SCALE		CHECKED FRANK ZUECH

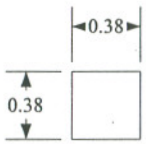
TABLE I: DATA MATRIX™ REQUIREMENTS

1. DOT PEEN MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027), 0.008-0.016 DEEP
2. LASERSHOT™ PEEN MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027), 0.008-0.016 DEEP
3. MICRO-MILL MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027), 0.024-0.032 DEEP
4. LASER BOND MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027)
5. LASER ETCH MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027)
6. GAS ASSIST LASER ETCH (GALE) MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027)
7. LASER ENGRAVE MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027), 0.008-0.016 DEEP
8. LASER INDUCE SURFACE IMPROVEMENT (LISI) MARKS IN DETAIL I.A PER NASA-HDBK-6003 (P027)
9. VIBRA-ETCH MARK IN DETAIL I.B PER OO-ALC/LITP PROCEDURE (NOT A MACHINE READABLE MARK)
10. IMPRESSION STAMP MARK IN DETAIL I.B PER OO-ALC/LITP PROCEDURE (NOT A MACHINE READABLE MARK)

DETAIL I.A*



DETAIL I.B*



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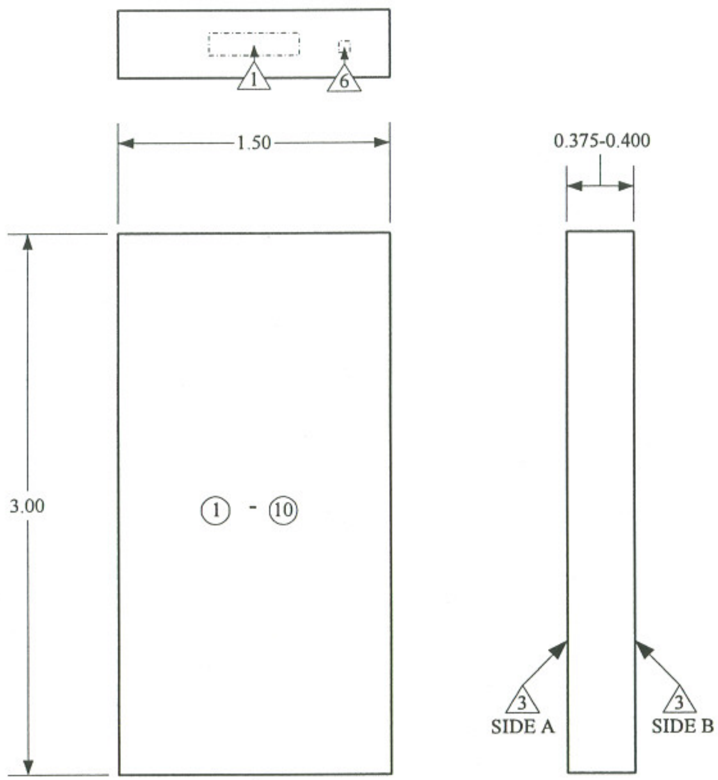
7	XXXXXXXXXXXXXXXXXXX7
8	XXXXXXXXXXXXXXXXXXX8
9	ALPHANUMERIC CHARACTER
10	ALPHANUMERIC CHARACTER

*DIMENSIONS INDICATE THE MAXIMUM ALLOWABLE AREA FOR MARKING

ALGLE PROGRAM	**TITLE** COUPON	**DRAWING NUMBER** A2A	**REVISION** C	**DIMENSIONS** ALL DIMENSIONS IN INCHES	**TOLERANCES** UNLESS OTHERWISE NOTED X.X = ± 0.1 X.XX = ± 0.05 ANGLES = ± 0.5°	**DRAWN** JOHN COATES
DPM EVALUATION	**MATERIAL** 7075-T7351 PER AMS 4078 (0.5 INCH PLATE)	**DATE** 3/9/01	**SHEET** 2 OF 2	**SCALE** NOT TO SCALE		**CHECKED** FRANK ZUECH

COUPON DRAWINGS: REVISION B

COUPON



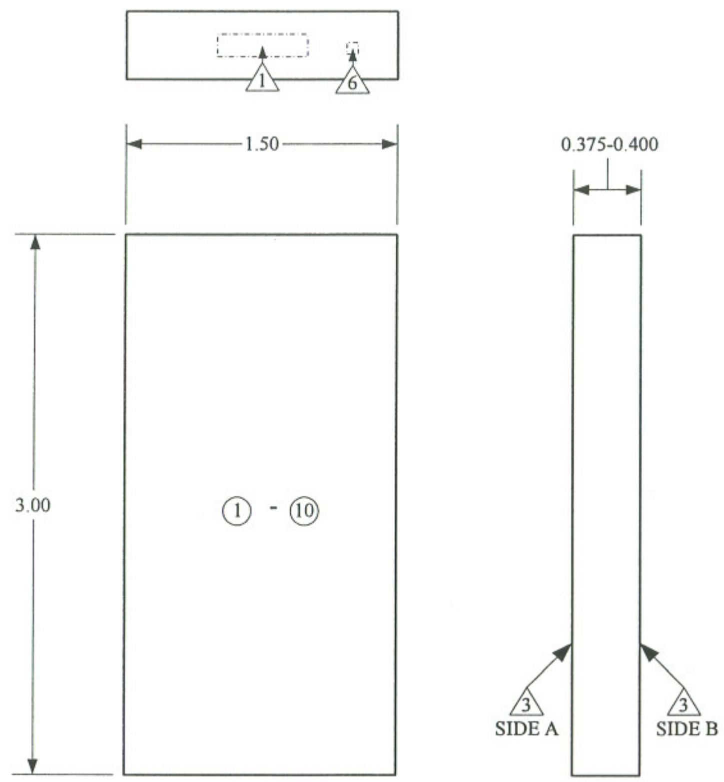
NOTES

1. SERIALIZE THE COUPONS S2A-O1 TO S2A-12 AT NOTED LOCATION USING 0.25 IMPRESSION STAMP,0.004-0.008 DEEP
2. HEAT TREAT AND PROCESS TO 260-280 KSI ULTIMATE TENSILE STRENGTH PER AMS-H-6875, MAXIMUM ALLOWABLE DECARBURIZATION 0.003
3. 0.025 125/64 M BEFORE 2, 125/64 M AFTER 2
4. BREAK ALL SHARP EDGES 0.005-0.015
5. FLUORESCENT MAGNETIC PARTICLE INSPECT PER ASTM E1444
6. FOR COUPONS WITH EVEN SERIAL NUMBERS: PERFORM ROCKWELL HARDNESS C TEST PER ASTM A370 AT NOTED LOCATION
7. FOR COUPONS WITH EVEN SERIAL NUMBERS: PERFORM SURFACE ROUGHNESS MEASUREMENT PER ASME B46.1

1 – 10 MARK SIDE A WITH DATA MATRIX™ SYMBOLS

ALGLE PROGRAM ALGLE	TITLE COUPON	DRAWING NUMBER S2A	REVISION B	DIMENSIONS ALL DIMENSIONS IN INCHES	TOLERANCES UNLESS OTHERWISE NOTED X.X = ± 0.1 X.XX = ± 0.05 ANGLES = ± 0.5°	DRAWN JOHN COATES
DPM EVALUATION	MATERIAL 4340 PER AMS 6415	DATE 10/18/00	SHEET 1 OF 1	SCALE NOT TO SCALE		CHECKED FRANK ZUECH

COUPON



NOTES

1. SERIALIZE THE COUPONS S2B-01 TO S2B-06 AT NOTED LOCATION USING 0.25 IMPRESSION STAMP,0.004-0.008 DEEP
2. HEAT TREAT AND PROCESS TO 260-280 KSI ULTIMATE TENSILE STRENGTH PER AMS-H-6875, MAXIMUM ALLOWABLE DECARBURIZATION 0.003
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   ii) INSPECT BEFORE AND AFTER MARKING 1 – 10
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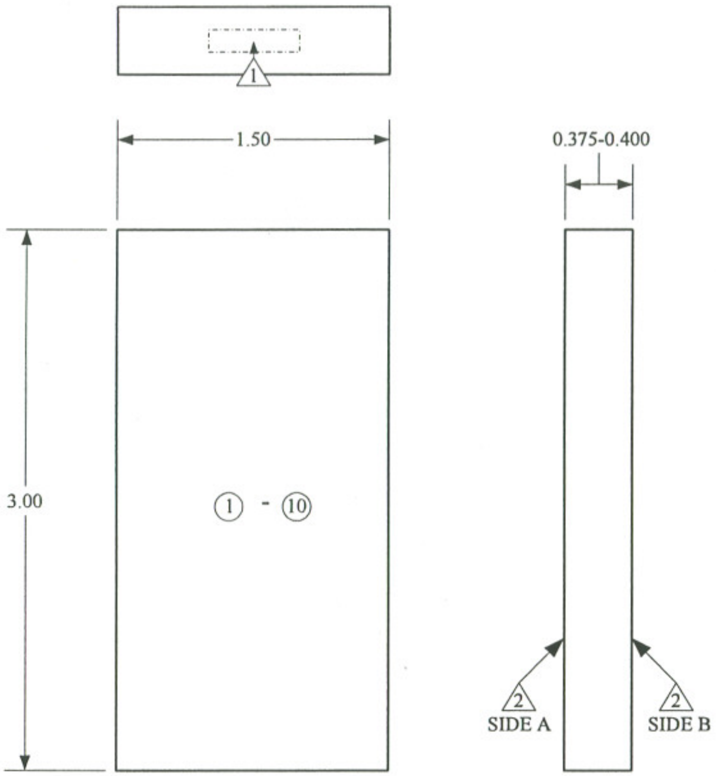
7. FOR COUPONS WITH EVEN SERIAL NUMBERS: PERFORM SURFACE ROUGHNESS MEASUREMENT PER ASME B46.1

1 – 10 i) MARK BEFORE 2
ii) MARK SIDE A WITH DATA MATRIX™ SYMBOLS

ALGLE PROGRAM ALGLE	TITLE COUPON	DRAWING NUMBER S2B	REVISION B	DIMENSIONS ALL DIMENSIONS IN INCHES	TOLERANCES UNLESS OTHERWISE NOTED X.X = ± 0.1 X.XX = ± 0.05 ANGLES = ± 0.5°	DRAWN JOHN COATES
DPM EVALUATION	MATERIAL 4340 PER AMS 6415	DATE 10/18/00	SHEET 1 OF 1	SCALE NOT TO SCALE		CHECKED FRANK ZUECH

COUPON



NOTES

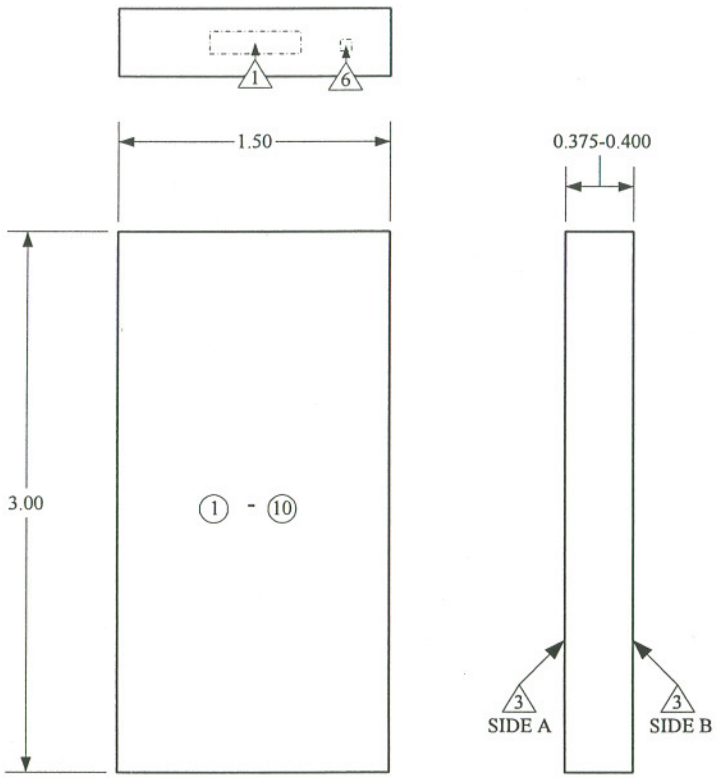
1. SERIALIZE THE COUPONS A2A-O1 TO A2A-12 AT NOTED LOCATION USING 0.25 IMPRESSION STAMP, 0.004-0.008 DEEP
2. 0.025 125/64 M
3. BREAK ALL SHARP EDGES 0.005-0.015
4. FLUORESCENT PENETRANT INSPECT PER ASTM E1417
5. FOR COUPONS WITH EVEN SERIAL NUMBERS: PERFORM CONDUCTIVITY TESTS PER MIL-STD-1537
6. FOR COUPONS WITH EVEN SERIAL NUMBERS: PERFORM SURFACE ROUGHNESS MEASUREMENT PER ASME B46.1

(1) – (10) MARK SIDE A WITH DATA MATRIX™ SYMBOLS

ALGLE PROGRAM ALGLE	TITLE COUPON	DRAWING NUMBER A2A	REVISION B	DIMENSIONS ALL DIMENSIONS IN INCHES	TOLERANCES UNLESS OTHERWISE NOTED X.X = ± 0.1 X.XX = ± 0.05 ANGLES = ± 0.5°	DRAWN JOHN COATES
DPM EVALUATION	MATERIAL 7075-T7351 PER AMS 4078 (0.5 INCH PLATE)	DATE 10/18/00	SHEET 1 OF 1	SCALE NOT TO SCALE		CHECKED FRANK ZUECH

COUPON DRAWINGS: REVISION A

COUPON



NOTES

1. SERIALIZE THE COUPONS S2A-O1 TO S2A-12 AT NOTED LOCATION USING 0.25 IMPRESSION STAMP,0.004-0.008 DEEP
2. HEAT TREAT AND PROCESS TO 260-280 KSI ULTIMATE TENSILE STRENGTH PER AMS-H-6875, MAXIMUM ALLOWABLE DECARBURIZATION 0.003
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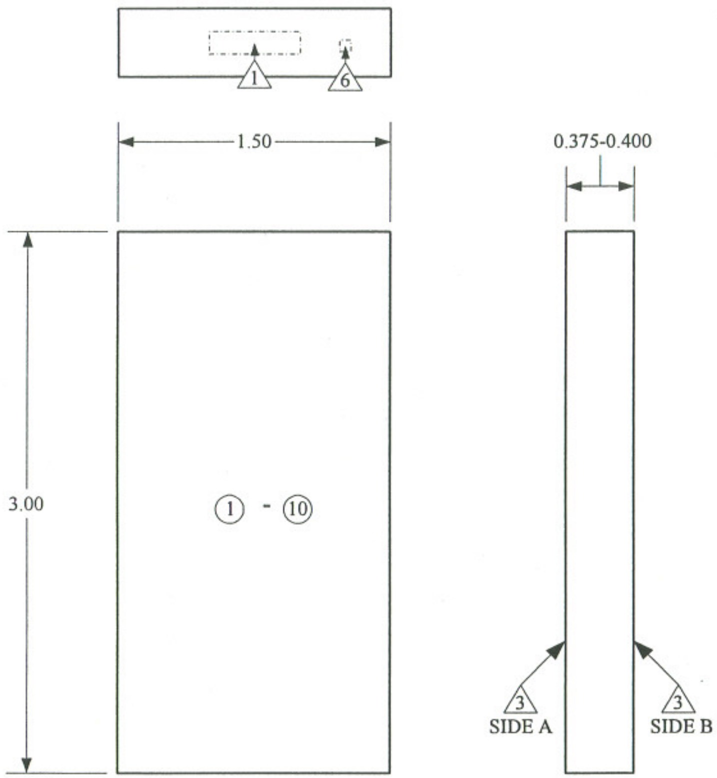
7. FOR COUPONS WITH EVEN SERIAL NUMBERS: PERFORM SURFACE ROUGHNESS MEASUREMENT PER ASME B46.1

1 – 10 MARK SIDE A WITH DATA MATRIX™ SYMBOLS

ALGLE PROGRAM	TITLE COUPON	DRAWING NUMBER S2A	REVISION A	DIMENSIONS ALL DIMENSIONS IN INCHES	TOLERANCES UNLESS OTHERWISE NOTED X.X = ± 0.1 X.XX = ± 0.05 ANGLES = ± 0.5°	DRAWN JOHN COATES
DPM EVALUATION	MATERIAL 4340 PER AMS 6359	DATE 9/28/00	SHEET 1 OF 1	SCALE NOT TO SCALE		CHECKED FRANK ZUECH

COUPON



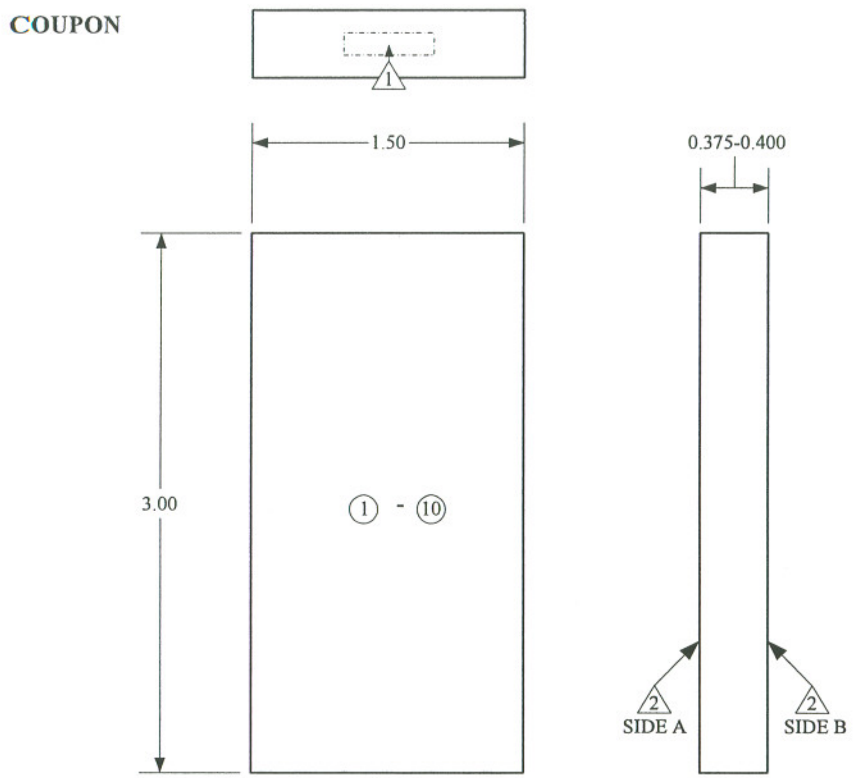
NOTES

1. SERIALIZE THE COUPONS S2B-01 TO S2B-06 AT NOTED LOCATION USING 0.25 IMPRESSION STAMP,0.004-0.008 DEEP
2. HEAT TREAT AND PROCESS TO 260-280 KSI ULTIMATE TENSILE STRENGTH PER AMS-H-6875, MAXIMUM ALLOWABLE DECARBURIZATION 0.003
3. 0.025 125/64 M BEFORE 2, 125/64 M AFTER 2
4. BREAK ALL SHARP EDGES 0.005-0.015
5. i) FLUORESCENT MAGNETIC PARTICLE INSPECT PER ASTM E1444
   ii) INSPECT BEFORE AND AFTER MARKING 1 – 10
6. FOR COUPONS WITH EVEN SERIAL NUMBERS: PERFORM ROCKWELL HARDNESS C TEST PER ASTM A370 AT NOTED LOCATION
7. FOR COUPONS WITH EVEN SERIAL NUMBERS: PERFORM SURFACE ROUGHNESS MEASUREMENT PER ASME B46.1

1 – 10 i) MARK BEFORE 2
ii) MARK SIDE A WITH DATA MATRIX™ SYMBOLS

ALGLE PROGRAM	TITLE: COUPON	DRAWING NUMBER: S2B	REVISION: A	DIMENSIONS: ALL DIMENSIONS IN INCHES	TOLERANCES: UNLESS OTHERWISE NOTED X.X = ± 0.1 X.XX = ± 0.05 ANGLES = ± 0.5°	DRAWN: JOHN COATES
DPM EVALUATION	MATERIAL 4340 PER AMS 6359	DATE: 9/28/00	SHEET: 1 OF 1	SCALE: NOT TO SCALE		CHECKED: FRANK ZUECH

COUPON



NOTES

1. SERIALIZE THE COUPONS A2A-O1 TO A2A-12 AT NOTED LOCATION USING 0.25 IMPRESSION STAMP, 0.004-0.008 DEEP
2. 125/64 0.025 √ M
3. BREAK ALL SHARP EDGES 0.005-0.015
4. FLUORESCENT PENETRANT INSPECT PER ASTM E1417
5. FOR COUPONS WITH EVEN SERIAL NUMBERS: PERFORM CONDUCTIVITY TESTS PER MIL-STD-1537
6. FOR COUPONS WITH EVEN SERIAL NUMBERS: PERFORM SURFACE ROUGHNESS MEASUREMENT PER ASME B46.1

(1) – (10) MARK SIDE A WITH DATA MATRIX™ SYMBOLS

ALGLE PROGRAM	TITLE COUPON	DRAWING NUMBER A2A	REVISION A	DIMENSIONS ALL DIMENSIONS IN INCHES	TOLERANCES UNLESS OTHERWISE NOTED X.X = ± 0.1 X.XX = ± 0.05 ANGLES = ± 0.5°	DRAWN JOHN COATES
DPM EVALUATION	MATERIAL 7075-T73 PER AMS 4141	DATE 9/28/00	SHEET 1 OF 1	SCALE NOT TO SCALE		CHECKED FRANK ZUECH